Cost of Environmental Pollution in Air Transport of Cargo Shipments

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***Abstract*- The paper presents the issue of cargo shipments in air transport including fuel economy and its impact on the environment. Organization of air transport is part of the problems of fuel savings in both the national and international areas. The article presents the issue of optimizing transport routes, including the central airport and regional airports, which helps to reduce carbon dioxide emissions and environment protection.**

Keywords*- *Cargo air transport; Air Transport Network; Transport Optimization

I. INTRODUCTION

Distribution process is one of the most important areas in the logistics chain[1] because it is designed to make the product available in time and is placed equivalent to the needs and expectations of customers. From a macroeconomic point of view, distribution refers to the process and structure of the goods movement from producers to recipients [13],[16],[20]. Therefore, distribution is a separate set of market channels and linkage between them. An important element and an integral part of the distribution system is transport system. Its main objective is optimal, in terms of accepted criteria, meeting transport operations reported in an area, through the implementation of the transport process [14], [17], [18],[19]. The transport process can be realized within one or more modes of transport. It can be realized on the basis of multimodal and intermodal technology. The efficiency of transport processes in distribution systems is affected accordingly by shaped transportation system, which can be identified with the transport system of the continent, region or country [1], [4], [7], [15].

Development of transport system in Poland follows from forecast of transportation needs as well as the adaptation of the system infrastructure standards and requirements of the European Union. The European Commission pays special attention to the need for sustainable development of transport and environmentally friendly transportation. Transport generates a lot of costs, part of which are paid by the users and the remaining burden all taxpayers. This means that the external cost is the cost that entities produce it but do not pay for it. These are the costs of inputs used to produce transport services, which are not borne by the buyer and the manufacturer of the service, but by a third entities i.e. the general public[5], [6].website.

II. ENVIRONMENTAL IMPACT OF TRANSPORT

An important aspect of economic development of any country is its impact on the environment. The impact of individual sectors of the economy on pollution of the environment is different. Also in the area of transport, there are significant differences in environmental pollution by different kinds of transport. Therefore, it is important to analyze climate risks, which causes air transport and will be one of the most dynamically developing transport modes in the near future.

Recent analysis published by *Word Resources Institute* (WRI) for issuers of greenhouse gases into the atmosphere indicate that in the structure, air transport plays a marginal role. The major greenhouse gas emitters include: production of electricity and heat based on fossil fuels, livestock, agriculture, industry, vehicles with internal combustion engines, oxidation processes, industrial processes, waste collection and disposal, air transport, and other modes of transportation. The percentage of individual emitters is shown in Fig. 1.

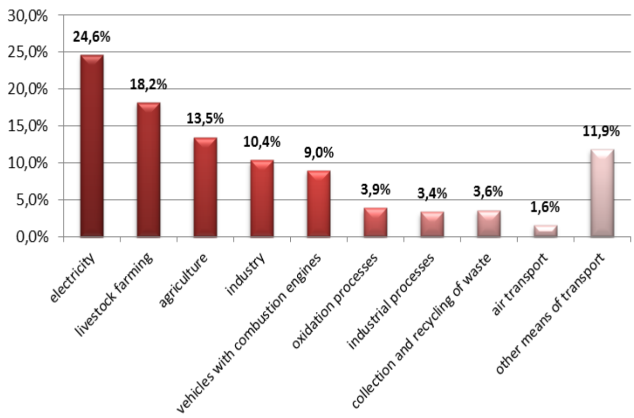

Fig. 1 The percentage of greenhouse gas emitters

** Source: develop their own based on Word Resources Institute*

Negative impacts of transport on the environment is now included in the overall costing of transport. External transport costs are the costs connected with negative for the environment and human life consequences of transport activity, in particular those relating to pollution of air, water and soil pollution, noise emissions, traffic accidents in the part are not covered by insurance and compensation system, occupancy of land[5]. In Poland, the costs of the negative impact of transport on the environment are estimated at approximately 29% of external costs [22]: costs of air pollution 11%, the costs of climate change 5%, 11% of the cost of noise and other environmental costs of 2%. The remaining 71% of external costs are the effects of human and material transport accidents. In total, it is estimated that the external costs are equivalent to 6% of GDP.

[1] Logistics chain is a network of links between companies involved in the processes and activities aiming at a flow of physical goods, which creates value for the purpose of this flow.

For all types of investment projects, including projects in the field of air transport, infrastructure is required to estimate the harmful effects of transport investment on the environment. The detrimental impacts of transport should be understood to be such factors as noise, air pollution, transport accidents or uncovered infrastructure costs that adversely affect the environment. The negative impact on the environment naturally leads to significant costs, both indirect (which are in the process of design, production, consumption, and destruction of means of transport and infrastructure) and direct (accidents, noise, vibration).

III. THE PROBLEM OF MODELING SYSTEMS IN AIR TRAFFIC

Air transport is a mode of transport, which can effectively influence the smooth flow of cargo. Transport processes in air transport are carried out based on the airports that are acts as a consolidation of cargo flow. One of the directions of airport development written in the transport policy of the country [10] is the inclusion of airports in the national and EU intermodal transport network. This strategy is partly the establishment of the European Commission, which aims to create efficient and effective transport system by implementing high quality solutions to the free movement of people, goods, and services in accordance with the principles of sustainable development. The idea of intermodal transport, which is based inter alia on the use in the transport more than one mode of transport, is fully consistent with the objectives of the European Strategy for sustainable development and transport policies in the European Union [21].

The problem of modeling the transport systems for air transport is analyzed in many studies of the literature [2], [11], [25]. [11] presents the problem of inter-modal transportation planning process and takes into account the air-loading terminals. This approach allows minimizing the execution time of transport, by taking into account transport operations carried out by air transport. A similar approach was presented in [2], in which the author solved the problem of optimal goods flow in air transport network using heuristic algorithms. Another class of problems is considered in [3], [8], [12] in which much attention is paid to increase the capacity of airports for freight shipments, minimize the execution time of transport, as well as optimize distribution systems in which the indicator of the quality assessment is processes realization cost. Issue concerning the decision support systems in the management of intermodal transport operations including classical optimization tools has been presented in [3]. The same problem with the use of simulation tools is presented in [9], [26]. The literature also considers the problem of strategic planning, which found its referencing such in [23], [24]. The authors treat the problem as an important element of effective management in the field of air transport planning. The measure of the proposed solutions are costs of single-transport tasks and costs of shipments system functioning.

IV. AIR TRANSPORT CARGO SHIPMENTS AND ITS IMPACT ON THE ENVIRONMENT

Air transport of goods is realized in nationally and internationally exchange of goods. Its advantage is the short duration of carriage. This is particularly important in the transport of goods sensitive to environmental change, perishable or recognized as dangerous. The main goods carried by air transport are: mail, industrial materials, pharmaceuticals, perishable goods, and animals. Among Polish airports, the highest turnover of goods is recorded in Warsaw. This is because of large concentration of shipping companies and airports here handle most air traffic in Poland. The development of air transport in Poland is not as dynamic as might be expected after Polish's accession to the European Union. The role of this type of freight transport in Poland is small, especially compared with Western European countries. Warsaw airport development is inhibited due to its central location (capacity constraints), and environmental constraints associated with noise emission standards. This causes development of other airports, which are slowly trying to meet market requirements. It should also be noted that the determinate value of airport development are operating costs. These costs can include fuel economy, sizeable accurate flight planning, and fuel consumption during the flight. In planning the amount of fuel needed, the type of plane along with its parameters, the economics of flight (mass of the plane after loading, rate of climb, cruise altitude, cruise speed, descent rate, number of approaches), the distance between airports, port distance airport alternative (backup) from the destination airport should be considered. Fuel affects the environment in the form of exhaust emissions. Selected indicators of fuel consumption and emissions for different plane types are shown in Figs. 2 to 5. Fig. 2 shows fuel consumption as a function of flight distance for the selected plane used to transport cargo. Other figures show emissions resulting from burning jet fuel. The analysis includes: nitrogen oxides, hydrocarbons, and oxides of carbon.

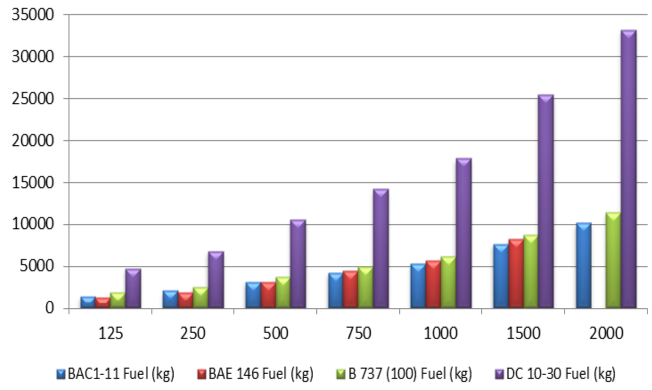

Fig. 2 Fuel consumption as a function of the distance flown

** Source: develop their own based on Word Resources Institute*

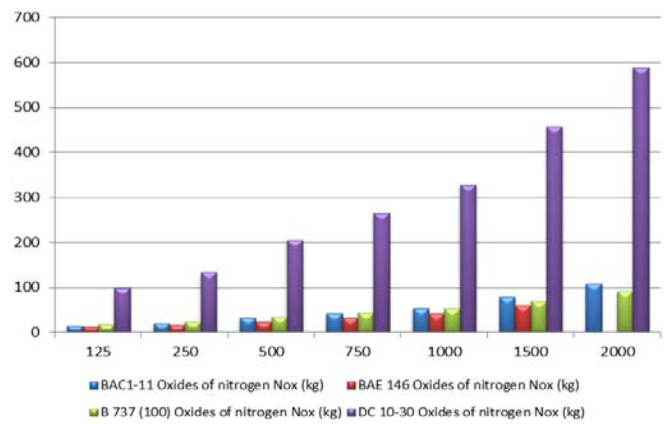

Fig. 3 Exhaust emissions of nitrogen oxides as a function of the distance flown

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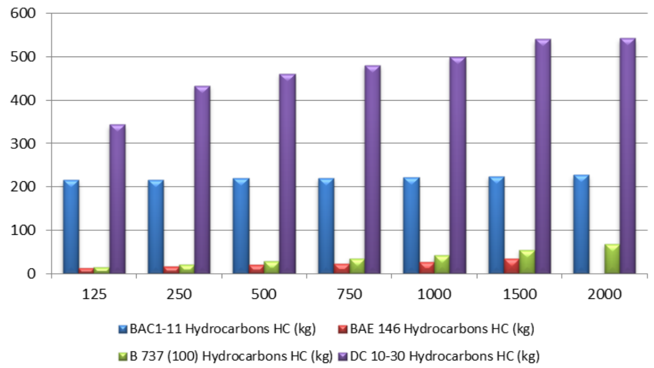

Fig. 4 Exhaust emissions of hydrocarbons as a function of the distance flown

Source: develop their own based on Word Resources Institute

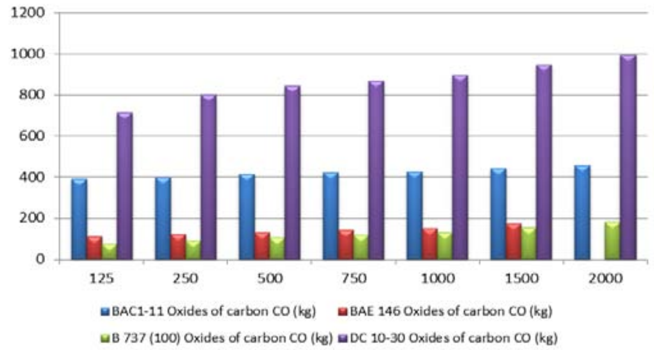

Fig. 5 Exhaust emissions of oxides carbon as a function of the distance flown

Source: develop their own based on Word Resources Institute

V. THE FORMALIZATION OF TRANSPORT SERVICE PROBLEM OF CARGO SHIPMENTS

For the purpose of modeling the transport service, the structure of the transport network of air transport is represented by a graph representing the nodes of the transport network of air transport and connections between them. Vertices of the graph give the interpretation of airports, while the graph arcs represent direct connections exist between airports (vertices of the graph). Model parameters are given in Table Ⅰ.

TABLE I MODEL PARAMETERS

Designation Parameter	Parameter Interpretation
$c^{SP}(s)$	Volume of $s-$ th Plane: $c^{SP}(s)\in\Re^{+}; s\in \boldsymbol{S}^{LOT}$
$cc^{SP}(s)$	Capacity of $s-$ th Plane: $cc^{SP}(s)\in\Re^{+}; s\in \boldsymbol{S}^{LOT}$
$sm^{PL}(l)$	Demand of $l-$ th Airport for the Supply of Goods $sm^{PL}(l)\in\Re^{+};\quad l\in \boldsymbol{L}^{LOT}$
$\delta^{CZ}(s,l)$	Loading Time Of $s-$ th Plane in $l-$ th Airport: $\delta^{CZ}(s,l)\in\Re^{+}; s\in \boldsymbol{S}^{LOT}, l\in \boldsymbol{L}^{LOT}$
$\delta^{CW}(s,l)$	Unloading Time of $s-$ th Plane In $l-$ th Airport: $\delta^{CW}(s,l)\in\Re^{+}; s\in \boldsymbol{S}^{LOT}, l\in \boldsymbol{L}^{LOT}$
CO^{PL}	Time Interval in which Service should be Start/ Stop in $l-$ th Airport: $CO^{PL}=\left\langle co'^{PL}(l), co''^{PL}(l);\quad \forall l: l\in \boldsymbol{L}^{LOT}\right\rangle$
MI^{PL}	Time Interval in which the Loads are Taken from the Cargo Terminalin Warsaw: $MI^{PL}=\left\langle \mu'^{PL}(l),\mu''^{PL}(l);\ \mu'^{PL}(l)\in\Re^{+},\mu''^{PL}(l)\in\Re^{+}, l\in \boldsymbol{L}^{LOT}\right\rangle$
$k(s)$	Cost of One Hour's Flight $s-$ th Plane: $k(s)\in\Re^{+};\quad s\in \boldsymbol{S}^{LOT}$
$\varepsilon^{CW}(s,l)$	Moment of Takeoff $s-$ th Plane from $l-$ th Airport: $\varepsilon^{CW}(s,l)\in\Re^{+}: s\in \boldsymbol{S}^{LOT}, l\in \boldsymbol{L}^{LOT}$
$\varepsilon^{CW}(s,l')$	Moment of Takeoff $s-$ th Plane from $l'-$ th Airport: $\varepsilon^{CW}(s,l')\in\Re^{+}: s\in \boldsymbol{S}^{LOT}, l'\in \boldsymbol{L}^{LOT}$

Source: develop their own based on Word Resources Institute

It was assumed that the airport will be numbered by index l, then $\boldsymbol{L}^{LOT}$ will be a set of airports numbers as: $\boldsymbol{L}^{LOT}=\left\{l:\quad l=\overline{1,L}\right\}$, where L is the size of its set $\boldsymbol{L}^{LOT}$.

Moreover, we assume that $l=1$ has an interpretation of the airport located in Warsaw and is the point of cargo shipments consolidation.

Connections between airports form a set $\boldsymbol{K}^{LOT}$, which has the form:

$$\boldsymbol{K}^{LOT}=\left\{(l,l'):\quad \xi(l,l')=1,\quad l,l'\in \boldsymbol{L}^{LOT}, l\neq l'\right\} \tag{1}$$

where $\xi(l,l')$ is a mapping defined on the Cartesian product sets $\boldsymbol{L}^{LOT}\times\boldsymbol{L}^{LOT}$, which elements of this product is assigned elements from a set of $\{0,1\}$ and $\xi(l,l')=1$, if between nodes l and l', $l\neq l'$ transport connection exists, and otherwise $\xi(l,l')=0$.

This notation allows the representation of the transport network structure of air transport as a graph $\mathbf{T}^{LOT}$, which has the form:

$$\mathbf{T}^{LOT}=\left\langle \boldsymbol{L}^{LOT}, \boldsymbol{K}^{LOT}\right\rangle \tag{2}$$

The nodes and connections of transport network are defined quantitative characteristics, e.g. the distance between airports, flight time, airport capacity, etc.

We assume that on the Cartesian product sets $\boldsymbol{L}^{LOT}\times\boldsymbol{L}^{LOT}$ given mapping d^{PL} conducting elements of the product in the set of positive real numbers $\Re^{+}$, i.e.:

$$d^{PL}: \boldsymbol{L}^{LOT}\times\boldsymbol{L}^{LOT}\longrightarrow\Re^{+} \tag{3}$$

where value $d^{PL}(l,l')\in\Re^{+}$ has the interpretation of the distance between airports l and l', $l\neq l'$, $l,l'\in \boldsymbol{L}^{LOT}\wedge\xi(l,l')=1$.

Set $\boldsymbol{S}^{LOT}$ set of numbers of plane which serving the carriage of cargo, has the form:

$$\boldsymbol{S}^{LOT}=\left\{s:\quad s=\overline{1,S}\right\} \tag{4}$$

where S is the size of its set $\boldsymbol{S}^{LOT}$.

On the Cartesian product of sets $\boldsymbol{L}^{LOT}\times\boldsymbol{L}^{LOT}\times\boldsymbol{S}^{LOT}$ given mapping cp^{PL} conducting elements of the product in the set of positive real numbers $\Re^{+}$, i.e.:

$$cp^{PL}: \boldsymbol{L}^{LOT}\times\boldsymbol{L}^{LOT}\times\boldsymbol{S}^{LOT}\longrightarrow\Re^{+} \tag{5}$$

where value $cp^{PL}((l,l'),s)\in\Re^{+}$ has the interpretation of the time of flight $s-$ th type of plane between airports l and l', $l\neq l'$, $l,l'\in \boldsymbol{L}^{LOT}\wedge\xi(l,l')=1$.

For the purpose of formulating the optimization task, we assume that on the Cartesian product sets $\boldsymbol{L}^{LOT} \times \boldsymbol{S}^{LOT}$ given mapping ζ conducting elements of the product in the set $\{0,1\}$, i.e.:

$$\zeta: \quad \boldsymbol{L}^{LOT} \times \boldsymbol{S}^{LOT} \longrightarrow \{0,1\} \tag{6}$$

and if $\zeta(l,s)=1$, then $l-$ th airport can accept $s-$ th plane that support for cargo shipments, otherwise $\zeta(l,s)=0$.

In order to define the decision variables we assume that the Cartesian product sets $\boldsymbol{K}^{LOT} \times \boldsymbol{S}^{LOT}$ given mapping conducting elements of the product in the set $\{0,1\}$, i.e.:

$$x: \quad \boldsymbol{K}^{LOT} \times \boldsymbol{S}^{LOT} \longrightarrow \{0,1\} \tag{7}$$

decision variable $x((l,l'),s)=1$, when (l,l') included in the route $s-$ th plane, otherwise $x((l,l'),s)=0$.

VI. MATHEMATICAL FORMULATION OF AN OPTIMIZATION TASK OF THE CARGO SHIPMENT SERVICE

Values of decision variable $x((l,l'),s)$ should be designated and satisfy the following constraints:

$$\sum_{l \in \boldsymbol{L}^{LOT}} \sum_{s \in \boldsymbol{S}^{LOT}} x((l,l'),s)=1, \quad \forall l': l' \in \boldsymbol{L}^{LOT} \tag{8}$$

$$\sum_{l' \in \boldsymbol{L}^{LOT}} \sum_{s \in \boldsymbol{S}^{LOT}} x((l,l'),s)=1, \quad \forall l: l \in \boldsymbol{L}^{LOT} \tag{9}$$

$$\sum_{l \in \boldsymbol{L}^{LOT}} x((l,l'),s) - \sum_{l' \in \boldsymbol{L}^{LOT}} x((l,l'),s) = 1, \forall s: s \in \boldsymbol{S}^{LOT} \tag{10}$$

$$\sum_{l \in \boldsymbol{L}^{LOT}} sm^{PL}(l) \sum_{l' \in \boldsymbol{L}^{LOT}} x((l,l'),s) \le c^{SP}(s), \forall s: s \in \boldsymbol{S}^{LOT} \tag{11}$$

$$\sum_{l \in \boldsymbol{L}^{LOT}} sm^{PL}(l) \sum_{l' \in \boldsymbol{L}^{LOT}} x((l,l'),s) \le cc^{SP}(s), \forall s: s \in \boldsymbol{S}^{LOT} \tag{12}$$

$$\begin{aligned} &\upsilon(l) - \upsilon(l') + L \sum_{s \in \boldsymbol{S}^{LOT}} x((l,l'),s) \le L-1, \\ &0 \le l \ne l' \le m, \upsilon(l), \upsilon(l') \in \Re^{+} \end{aligned} \tag{13}$$

$$x((l,l'),s) \in \{0,1\}, \quad l,l' \in \boldsymbol{L}^{LOT}, s \in \boldsymbol{S}^{LOT} \tag{14}$$

$$\begin{aligned} &\varepsilon^{CW}(s,l') = x((l,l'),s)\, max \begin{Bmatrix} \varepsilon^{CW}(s,l) + \\ cp^{PL}((l,l'),s), co'^{PL}(l') \end{Bmatrix} + \delta^{CW}(s,l), \\ &l,l' \in \boldsymbol{L}^{LOT}, s \in \boldsymbol{S}^{LOT} \end{aligned} \tag{15}$$

$$\begin{aligned} &co'^{PL}(l) \le \varepsilon^{CW}(s,l) - \delta^{CZ}(s,l) \le co''^{PL}(l), \\ &\forall l: l \in \boldsymbol{L}^{LOT}, \forall s: s \in \boldsymbol{S}^{LOT} \end{aligned} \tag{16}$$

which determine the minimum cost of goods transport to airports presented as follows:

$$F(\boldsymbol{X}) = \sum_{s \in \boldsymbol{S}^{LOT}} \sum_{l \in \boldsymbol{L}^{LOT}} \sum_{l' \in \boldsymbol{L}^{LOT}} cp^{PL}((l,l'),s) x((l,l'),s) k(s) \tag{17}$$

VII. A CASE STUDY OF AIRPORT TRANSPORT SERVICE

The verification of problem of optimizing cargo shipments transport in air transport, carried out on the example of central airport in Warsaw, and eleven regional ports located on Polish territory. Polish location offers opportunities between landings in international air transport, also central airport in Warsaw can be used as a center for consolidation and deconsolidation of loads in cargo shipments transport between regional airports. For the purposes of modeling cargo transport in air, transport model of transport network of air transport was developed, taking into account the central airport in Warsaw and regional airports. The calculations take into account the relationship between airports located in those cities: Warsaw, Krakow, Katowice, Wrocław, Poznan, Lodź, Gdańsk, Szczecin, Bydgoszcz, Rzeszow, Zielona Gora, and Szczytno. Moreover, in the calculation, we take into account load times, partial or total unloading of plane at the regional airport. Time of ground handling of plane and time of flight between airports were also included. Table Ⅱ summarizes the size demands (size of cargo to be delivered to regional airports) collection points (regional airports).

TABLE Ⅱ SERVICE POINTS AND SIZE OF THEIR NEEDS (PART OF TABLE NEEDS)

No. Airport	Volume of Demand of Collection Point	
	[Kg]	[Cu][1]
1	3598	12
(…)	(…)	(…)
12	1376	5

[1] air transport container unit

Source: develop their own based on statistics

The solution was obtained using a computer program (*The optimization of routs delivery*), representing an important element in decision making process about transportation planning. The optimization method uses a random allocation of resources, supported by the evolutionary method with a limited set of genetic algorithms allows the target to improve the solution. So, in theory, the result is the best schedule from the set of admissible schedules.

With the right formulation of the optimization tasks and the use of optimization tools, optimal route for the operation of regional airports have been obtained:

Flight routes of aircraft (airplanes) - results are based on analysis of one day:

Flight route no. 1:< 1, 2, 3, 1 >
Flight route no. 2:<1, 5, 7, 9, 1 >
Flight route no. 3:<1, 6, 8, 11, 1 >
Flight route no. 4:<1, 10, 12, 4, 1 >

Interpretation of the routes between airports:

- Warsaw, Katowice, Lodź , Szczytno, Warsaw
- Warsaw, Rzeszów, Krakow, Zielona Góra, Warsaw
- Warsaw, Wrocław, Poznan, Bydgoszcz, Warsaw
- Warsaw, Poznan, Szczecin, Gdańsk, Warsaw

The length of the routes of various relationships（Fig. 6）:

Flight route no. 1:	802 km
Flight route no. 2:	1154 km
Flight route no. 3:	804 km
Flight route no. 4:	1047 km
Total:	3807 km

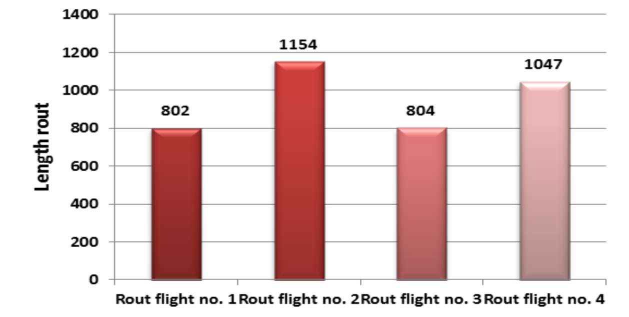

Fig. 6 The lengths of the routes of the various relationships

Source: develop their own

The longest route is route No. 2 - the ratio of: Warsaw, Rzeszow, Krakow, Zielona Gora, Warsaw, the length of the route is 1154 km, while the shortest route is the route no. 1 - the ratio of: Warsaw, Katowice, Lodz, Szczytno, Warsaw. Determining routes of individual relationship was based on available statistical data on the volume of cargo handling at airports and transport directions (Fig. 7).

Fig. 7 Diagram of the routes in various relations

Source: develop their own

Taking into account the environmental aspects for analyzed case study the amount of fuel consumed was calculated for each flight paths (Fig. 8) and the total transport service. The analysis was conducted on the example of two planes BAC1-11 and B 737 (100). Total fuel consumption for BAC1-11 plane is 19691.7 kg and for plane B 737 (100) is 22740.1 kg.

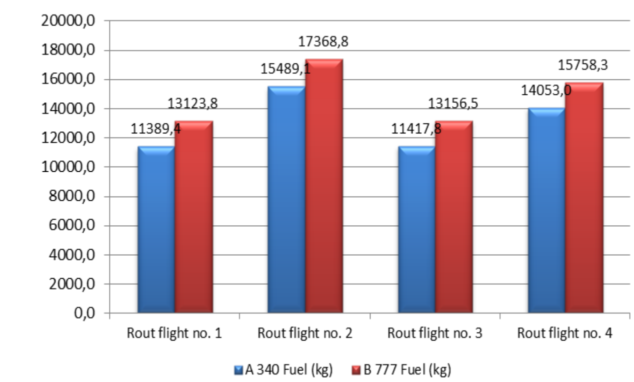

Fig. 8 Fuel consumption for the different routes

Source: develop their own

As mentioned above, the amount of fuel consumed during transportation process affects the environment as an exhaust emissions. Fig. 9 shows emission to environment for the analyzed case study.

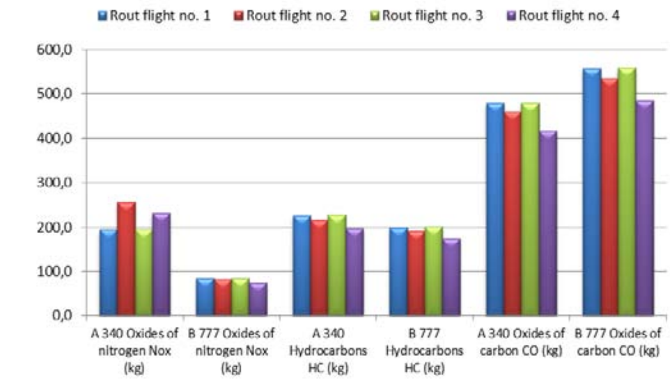

Fig. 9 The values of exhaust emission in case study

Source: develop their own

Values of exhaust emission are different and result from the characteristics of plane and the distance flown. The analysis shows that most chemicals are released into environment such as carbon oxides and hydrocarbons.

VIII. CONCLUSIONS

The subject of this research is the realization of services in cargo transportation between regional airports. The analysis assumes that the central airport from which the separation of charge goes to regional airports is an airport in Warsaw. The main factors that influence the development of air transport is the cost of operation of airports, airfields appropriate infrastructure (enabling a massive cargo planes), and cargo storage area with adequate infrastructure. Another significant issue is legal considerations of duty and tax laws which affect the service time of aircraft.

An important aspect of air transport development is its impact on environment, so when deciding the air transport, choosing a correct type of plane for this service should be taken into account. This paper presents a methodology rationalize air cargo in air transport and the calculation of exhaust emissions for different planes.

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